IJRCS

International Journal of Robotics and Control Systems
Vol. 4, No. 1, 2024, pp. 105-124
ISSN 2775-2658
http://pubs2.ascee.org/index.php/ijrcs

ASCEE

Industry 4.0 Readiness Trends: A Bibliometric and Visualization Analysis

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ARTICLE INFO

Article history
Received December 05, 2023
Revised February 04, 2024
Accepted February 15, 2024

Keywords
Industry 4.0;
Manufacturing;
Industry Readiness;
Business;
Technology

ABSTRACT

The Industrial Revolution 4.0 signifies a pivotal change in industrial paradigms, integrating advanced technologies like the Internet of Things (IoT), artificial intelligence (AI), robotics, and big data into production processes. This research aims to analyze the growth and readiness in industry for these changes through a detailed bibliometric analysis. It quantitatively tracks the expansion of Industry 4.0 readiness research, including publication counts, citation trends, and thematic shifts, reflecting heightened academic and industrial interests. A clear definition of Industry 4.0 readiness is provided, focusing on metrics and criteria used for assessment. The paper identifies key contributions and novel insights of the research, emphasizing its practical implications for industry and academia. It examines elements influencing Industry 4.0 readiness, such as infrastructure, policy, and workforce preparedness, offering a comprehensive overview of challenges. The practical implications of our findings are presented, suggesting actionable strategies for stakeholders. This research also highlights the gaps in the current literature, which offers a thorough and multidimensional understanding of Industry 4.0 readiness, its influences, and its impact on the global industrial system.

1. Introduction

Industry 4.0 created a wave of revolution in the industrial sector that significantly changed global economic patterns [1], [2]. In this period, almost all aspects of our lives have been shaken by advances in digital technology and connectivity, and this influence is no exception in the industrial world [3], [4]. Readiness, also known as "readiness," is a critical factor that plays a key role in determining a company’s success or failure amidst the turbulent changes of the Industry 4.0 era [5], [6].

In the context of Industry 4.0, readiness refers to the preparedness of organizations to adapt to technological changes, such as automation and data exchange in manufacturing technologies. This preparedness encompasses the ability of organizations to integrate advanced technologies, such as digital manufacturing and assembly systems, robotics, and automation, into their operations [7]-[10].

Readiness in the Industry 4.0 era involves comprehensive considerations regarding the preparation of companies [11], [12], government [13], [14], and society [15], [16] to face fundamental changes triggered by advanced technological advances. These readiness aspects include not only the company's ability to adopt the latest technology, but also focus on developing human resources who have relevant skills and knowledge [17]. Apart from that, readiness includes efforts to formulate business strategies that are in line with the ever-changing dynamics of Industry 4.0 [18].

Success in preparing will play a crucial role in enabling companies to achieve competitive advantage [19], [20]. By adopting the latest technology, companies can optimize their production processes [21], increase operational efficiency [22], and more adaptively respond to changing market demands that continue to develop [23]. In other words, Industry 4.0 readiness is not just about keeping up with technological trends [24], but also involves holistic strategic steps to ensure that companies not only survive [25], but also thrive in an increasingly complex and changing business environment. this [11].

The significance of readiness in Industry 4.0 is also seen in a broader social and economic framework [26]. The entire society will face a transformation that will have a major impact on the way they interact with technology [27], do work [28], and engage in economic activities [29]. Therefore, the concept of readiness is not only limited to technical preparation, but also includes aspects of understanding, developing skills, and cultivating attitudes that are responsive to changes that will occur [30]. In discussing industry 4.0 readiness, we must also consider the ethical and social impacts of using advanced technology [31], as well as how to ensure that policies and regulations create an adequate framework to protect individual rights and privacy [32].

Thus, industry 4.0 readiness is a deep and important topic that describes the challenges and opportunities faced by the industrial world and society in facing the ongoing technological revolution [33]. This readiness is key to fully exploiting the potential offered by Industry 4.0 and to answering crucial questions about how we will guide human civilization into an increasingly connected and automated future [34], [35].

The development of robotic technology has become an integral part of the history of the industrial revolution [36]. Robotics, as a scientific discipline, includes the design, construction, operation, and use of robots. In the context of the Industry 4.0 era, the role of robotics is increasing because this technology brings a high level of automation, flexibility and artificial intelligence to various production processes and industrial sectors [37], [38]. Robots equipped with artificial intelligence can interact adaptively with the surrounding environment, carry out complex tasks, and significantly increase efficiency in production processes [37], [39].

The role of robotics in the context of Industry 4.0 readiness has a very important impact. Advanced robots, including collaborative robots and autonomous robots, have become an integral part of various production processes in sectors such as manufacturing, logistics, healthcare and other fields [26]. The use of these robots involves carrying out a variety of tasks, such as assembly, moving goods, inspections, predictive maintenance, and even surgical operations [40].

The advantages of these robotics are not only limited to their ability to operate in harsh industrial environments, but also to their ability to handle repetitive tasks with a high degree of accuracy [37]. Furthermore, robotics" adaptive intelligence allows them to adapt to changing environmental conditions, making them an invaluable asset in the Industry 4.0 era [41].

Readiness to embrace and utilize robotic technology in Industry 4.0 is very important [29]. This is confirmed by several main reasons. First, in the context of production efficiency, robotic technology is able to optimize production processes by reducing cycle times, minimizing errors, and can operate non-stop for 24 hours [34]. Additionally, in efforts to improve quality, the ability of robotics to carry out tasks with high accuracy makes a significant contribution to the production of higher quality and consistent products [42].

The aspect of the lack of human labor is also the main factor that drives the importance of adopting robotic technology [37]. In some situations, robotics can replace heavy or dangerous human work, helping to reduce the potential risk of injury. Furthermore, in facing the challenges of innovation and competitiveness, companies that use robotic technology have greater opportunities to create innovative products, maintaining their competitiveness in the competitive global market [43].

Security readiness is also an aspect that cannot be ignored. In this context, preparedness involves managing risk and adequate safety in the application of robotic technology, especially in industries that adopt high levels of automation [44]. Therefore, Industry 4.0 readiness in responding to these security challenges is very important so that the use of robotic technology runs safely and effectively in a highly automated industrial environment [1].

In the Industry 4.0 era, appropriate readiness in the use of robotic technology will help companies face change, increase efficiency and achieve better results [30]. Therefore, careful understanding and preparation in adopting technology is an important step for companies and industries in facing this increasingly automated and connected industrial era [34].

1.1 Industry 4.0

The history of the industrial revolution is in accordance with Fig. 1. The first industrial revolution began at the end of the 18th century with the introduction of the steam engine as the main source of power [45]. This innovation replaces manual production methods with mechanized machines in the textile, mining and manufacturing sectors [6]. The steam engine not only increased production efficiency but also opened the door to the development of large factories. This era fundamentally changed the way humans produced goods, bringing about profound economic and social changes [46].

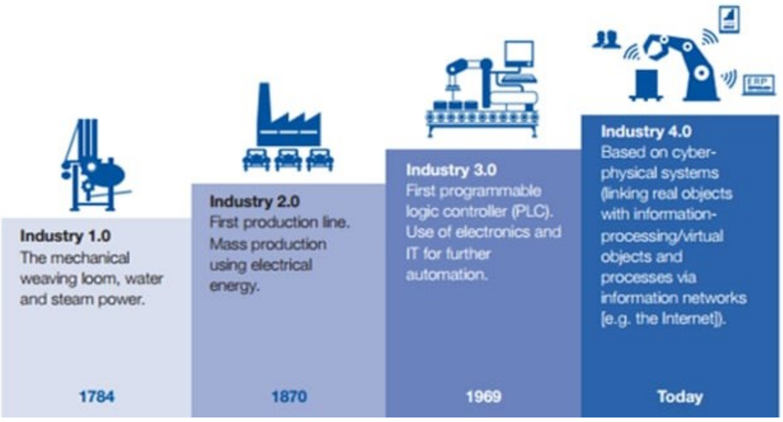

Fig. 1. History of the industrial revolution

The second industrial revolution began at the end of the 19th century with the use of electric power and the development of machine technology [47]. Factories began to adopt assembly lines and mass production concepts, especially in the automotive industry [48]. These advances brought about significant changes in the scale of production and fueled industrial growth with an emphasis on efficiency and mass production [49]. Meanwhile, the third industrial revolution occurred in the mid-20th century and was characterized by the use of computer technology. Computers began to be used in design and production, paving the way for further automation. Numerical control (CNC) systems emerged, enabling high precision production in a variety of industries [50]. Additionally, information technology is starting to be applied in management and administration, changing the way organizations operate [51].

Current developments in information and communication technology, especially involving advances in internet technology, have attracted the attention of many practitioners who are trying to utilize them in the manufacturing process [52]. The company seeks to integrate machines, equipment and labor to achieve various benefits [53]. A new idea known as Cyber-Physical System (CPS) is emerging as a concept that combines Internet of Things (IoT) technology with a manufacturing ecosystem [20], [54]. This introduced a new era in industrialization, which is recognized as a very significant paradigm shift in the manufacturing sector and is known as the 4th Industrial revolution or Industry 4.0 [23].

Industry 4.0 started in the early 2010s and is the current digital era. Artificial intelligence, Internet of Things (IoT) [20], big data [51], and cloud computing are taking center stage [48]. Smart factories are starting to emerge, with end-to-end connected devices and systems [55]. This concept not only optimizes production efficiency but also opens the door to product personalization, predictive maintenance and adaptive production systems [56]. Industry 4.0 marks a profound shift in the production paradigm by combining digital technology and artificial intelligence to create a smarter [57] and more efficient manufacturing environment [58].

Advancements in robotics play a pivotal role in achieving readiness in various sectors within the context of Industry 4.0. It includes manufacturing, agriculture, healthcare, and automotive industries, are instrumental in driving the technological transformation and readiness required for Industry 4.0. Robotics, including various types such as surgical robots, assistive robots, and industrial robots, have reached high levels of technological readiness, making them integral to the transformation of industries [59]. The integration of robotics in the manufacturing sector is a key component of Industry 4.0, enabling the development of cyber-physical systems and the implementation of automation technologies [60]-[62]. Robotics, particularly in the form of autonomous mobile robots, has been identified as a critical technology for addressing challenges in agricultural operations, demonstrating its significance in enhancing readiness in the agriculture sector [63]-[65].

Furthermore, the safety control and dependability of industrial robots have been emphasized, highlighting the importance of ensuring the safe and reliable operation of robots in industrial settings [66], [67]. In the healthcare sector, interactive robots have been assessed for their technology readiness and adoption potential, indicating their potential to contribute to readiness in the welfare and health sectors [68]. Additionally, the use of aerial robots in industrial manufacturing and the design of robotized cells for part assembly in the automotive industry underscore the diverse applications of robotics in achieving Industry 4.0 readiness [69]. Moreover, the development of collaborative robots and the implementation of distributed ledger technologies in robotics further exemplify the evolving landscape of robotics and its role in shaping the readiness of industries [70].

The integration of robotics in Industry 4.0 presents both opportunities and challenges. Opportunities include technological advancements, advancements in soft robotics, transforming clinical care, digital twin for human-robot interactions, symbiotic relationship with lean manufacturing, smart farming technology, and ethical considerations. Challenges encompass labor impact and environmental effects, technology readiness and adoption, worker training and acceptance, customization and Industry 4.0, ethical climate and turnover intention, competency measures and soft skills, risk assessment and safety standards. Therefore, while robotics within the context of Industry 4.0 offers significant opportunities for technological advancement and innovation, addressing challenges related to labor impact, ethical considerations, worker training, and safety standards is crucial for the successful integration of robotics across various sectors.

1.2 Industry 4.0 Readiness

Industry 4.0, as a significant evolution in the world of manufacturing, is driven by a number of concepts and technologies that change the traditional paradigm [71]. Industry 4.0 readiness involves a deep understanding of the core elements that form the foundation for adopting [72] and integrating advanced technologies [73], [74]. One of the most basic elements is connectivity via the Internet of Things (IoT) [22]. This connectivity allows devices, machines and systems to be networked [75], creating a connected ecosystem that enables efficient data exchange and supports real-time operational monitoring [76].

Apart from connectivity, big data and analytics play an important role in preparation for Industry 4.0 [51]. By managing and analyzing data at scale, companies can understand patterns, identify opportunities for improvement, and increase operational efficiency [77], [78]. Data analytics is becoming a critical tool for data-supported decision making, providing the information power needed to face the challenges and opportunities in this digital era [79].

Cyber-physical system integration is one of the requirements for Industry 4.0 readiness [80]. Involves hardware and software. This creates an environment where the physical and digital worlds interact [81]. This system optimizes the automation and responsiveness of production processes, efficiency and facilitates adaptation to changing market needs [37].

Additive manufacturing technology, or 3D printing, is becoming a key element in industry 4.0 readiness [82]. The ability to print products with low costs, complex designs, and a high degree of production flexibility are key drivers of innovation in manufacturing processes [30]. 3D printing provides the freedom to design and create products in ways that were previously difficult to achieve [5].

Cybersecurity cannot be ignored in industry 4.0 readiness [46]. With increasing levels of connectivity and more intensive use of data, protection against cyber attacks and data privacy have become increasingly important [28]. Investments in cybersecurity involve implementing high-security protocols to protect vital systems and data [83].

Developing workforce skills is crucial. Industry 4.0 requires a workforce that can adapt quickly to technological changes [16]. Training and skills development are key steps to ensure that the workforce has the knowledge and skills necessary to operate and innovate in an increasingly automated and digitalized manufacturing environment [21], [84]. Thus, Industry 4.0 readiness is a progressive step in creating an industrial ecosystem that is adaptive, innovative and responsive to technological and market changes [18]. Several definitions of Industry 4.0 are in accordance with Table 1.

Table 1. Definition industry 4.0 readiness

Author	Definition
[85]	Industry 4.0 Readiness is the readiness for comprehensive transformation of all aspects of production in industry through combining digital and internet technology with conventional industry
[82]	Industry 4.0 readiness is a condition for individuals or organizations to be able to adapt and be able to use and utilize technology for daily activities
[46]	Industry 4.0 readiness is measuring the knowledge and capabilities of individuals or organizations regarding the resources needed to start a process and be able to keep up with the latest technological advances.

Given the importance and implications of all these issues for destination management, this research objective is to evaluate the scope and importance of Industry 4.0 readiness. The research will address the following key questions.
RQ_1: How is scientific knowledge about Industry 4.0 readiness developing?
RQ_2: What is the geographic distribution?
RQ_3: What authors, journals and scientific articles are the most influential?
RQ_4: What is the intellectual structure?

2. Method

2.1 Bibliometric Data

To identify relevant references, a systematic review was conducted in Scopus by applying the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement guidelines [86]. Following [87], the term "industry 4.0 readiness" becomes the basis of the search strategy, which in this case is combined with "trend". To expand and complete the search equation, other more specific terms related to robot-based smart technology were added.

Industry Readiness 4.0 refers to the readiness of a country, industry, or organization to adopt and utilize advanced technologies such as artificial intelligence , Internet of Things (IoT), big data, robotics, etc. to increase productivity, efficiency, and innovation in industrial processes [88]. There are several factors that encourage the formation of readiness industry 4.0, such as technological developments [89], globalization [1], innovation [4], [90], and digital transformation [44]. Awareness of the benefits of advanced technology and the need to compete in the digital era is the impetus behind the change towards industry readiness 4.0.

Furthermore, studies had to meet a series of inclusion and exclusion criteria to be eligible [91],[92]: (1) no time range was specified, and publications were indexed to November 13, 2023, the date the consultation took place is included; (2) only peer-reviewed articles published in scientific journals were included because they are considered "certified knowledge," subject to critical review and approval by other researchers [93], (3) no thematic area filter was applied due to the transversal nature of tourism, and (4) only articles in English were considered, because the natural language processing (NLP) algorithm used by the software used for the analysis does not support other languages (Table 2).

Table 2. Bibliometric reference search methodology

Search terms	Industry 4.0 Readiness
Search field	Article title, Abstract, Keywords (Scopus)
Query string	("Industry 4.0") and ("Industry 4.0 Readiness")
Period time	All time
Document type	Journal article
Thematic area	All theme
Language	Indonesia
Search date	November 2023

After these criteria were applied, a search carried out in Scopus produced 140 results. Of note, a single bibliographic database was compiled in Excel to identify and eliminate duplicates (via digital object identifiers (DOIs) and bibliographic reference titles). Scopus duplicate records were prioritized for the final database because Web of Science only includes the first author of each cited document and, therefore, does not consider other co-authors for co-citation analysis.

2.2. Bibliometric Analysis

Bibliometrics is a part of scientometrics that applies mathematical and statistical methods to scientific literature and the authors who produce it, with the aim of studying and analyzing their activities [94]. Bibliometric methods are classified as evaluative or relational [95]-[97]. Evaluative techniques focus on the impact of academic studies that evaluate performance with measures of productivity, impact, and hybrid metrics [98]. Citations are a fundamental impact metric, and their main goal is to identify the most influential publications, authors, and documents in a particular research field [99]. Relational techniques explore relationships in research, such as the structure of the research field, the emergence of new topics and methods, and national and international patterns of author collaboration [96]. In this work, two techniques of this type are used: co-citation and co-word analysis.

Network visualization is a graphical representation of the relationships between entities in a network, such as co-occurrence relationships between words in a text or co-authorship relationships between authors in a scientific publication [100]. Network visualization allows users to visualize the network in the form of a graph, where each entity is represented as a node and the relationships between entities are represented as edges between the nodes [101]. This network visualization helps users understand the structure, patterns and relationships in data, as well as identify groups or clusters of interrelated entities.

Overlay visualization in the context of VOSviewer refers to a visualization technique that allows users to add additional information or layers to an existing network visualization [102]. Overlay visualization is often used to highlight or mark certain entities in a network graph. This technique facilitates deeper analysis of structures and patterns in data networks, and allows users to explore relationships between entities and additional attributes more interactively.

Co-occurrence is the joint appearance of two or more entities in a text corpus or dataset [103]. Co-occurrence analysis is used to identify and visualize the relationships between these entities in the form of a network graph. Each entity is represented as a node in the graph, and co-occurrence relationships between entities are represented as edges between nodes [104]. This makes it easier for users to understand the structure and patterns in the data, as well as identify groups or clusters of entities that frequently appear together.

Co-authorship is a collaborative relationship between two or more authors in writing a scientific work or other publication [105]. Co-authorship analysis is used to identify and visualize collaborative relationships between authors in the form of network graphs. Co-authorship analysis allows users to understand collaboration patterns between authors, identify groups of authors who frequently collaborate, as well as analyze the structure of collaborative networks in a particular research field.

Co-citation is a co-occurrence relationship that occurs when two items from existing literature are cited together by a third party [106], [107], in this case, one author citing two others [108], [109]. This type of analysis assumes that there is a thematic affinity between two or more co-cited authors and that the greater the frequency of co-citations, the greater the similarity between them. The aim is to determine the central researcher of a particular scientific discipline based on citations with others.

2.3. Visualization of Results

References made by some authors to others, whether between journals or other types of documents, can be represented by graphs with a network structure [110] consisting of two fundamental elements: nodes, which represent articles, authors, keywords, etc., and links, also called edges, that connect one or more nodes to each other. To avoid duplication in notes and to correct inconsistencies, it is necessary to develop a thesaurus for writers and to normalize keywords (singular and plural, in American and British English, etc.).

To build, visualize and explore author co-citation networks, the software VOSviewer, developed at Leiden University, was used [111]. This program provides visualization of bibliometric networks through distance-based maps such that the distance between two nodes reflects the strength of the relationship between them. Based on bibliometric databases, VOSviewer performs cluster analysis, grouping each node according to proximity or distance patterns [111], obtaining groups or clusters of similar nodes as a result, differentiated by color.

3. Result and Discussion

3.1. The Evolution of Literature

Fig. 2 shows the annual frequency of publications, which uses graphs to analyze the evolution of the literature. The time period used to see the annual evolution is nine years, between 2015 and 2023. From 2015 to 2019 there were still few documents discussing industry 4.0 readiness. Then, in 2020 and 2021 there was a significant increase in the number of documents discussing industry 4.0 readiness, namely 31 documents. However, in 2022 the number of documents discussing Industry 4.0 readiness will decrease to 19 documents. Then, documents using the industry 4.0 readiness variable increased again to 31 documents in 2023. The most documents regarding the industry 4.0 readiness variable occurred in 2020, 2021 and 2023, namely 31 documents.

Table 3 shows the distribution of the number of documents by country or region. This provides an overview of the geographically distributed Industry 4.0 readiness documents. These works come from various different countries. The country with the most documents regarding Industry 4.0 readiness is Malaysia with 19 documents cited 170 times. India is in second place with the most documents with 14 documents and 282 quotes cited. Furthermore, Indonesia is in third place with 11 documents and cited 59 times. The next ranking is Hungary with the number of documents, namely

10 and cited 169 times. Furthermore, the Czech Republic has 8 documents and has been quoted 115 times. Next, Germany has 896 quotes from 8 documents. Furthermore, Italy and the United Kingdom both had 7 documents and were cited with 246 and 34 citations respectively. Apart from that, Brazil is in ninth place with the highest number of documents with 5 documents and is followed by Portugal in tenth place with 4 documents. The document regarding industry 4.0 readiness which has the highest number of citations is held by Germany with 896 citations in just 8 documents.

Furthermore, the institutions that have the highest number of documents discussing Industry 4.0 readiness are Prague University of Economics and Business, Pannon Egyetem, and Universiti Malaysia Perlis, each of which has 5 documents. The next ranking has a total of 4 industry 4.0 readiness documents, namely Universiti Kebangsaan Malaysia, Univerza v Mariboru and Számítástechnikai és Automatizálási Kutatóintézet. Ranks seven to ten have a total of 3 documents and are filled by Universiti Sains Malaysia, Universiti Teknologi PETRONAS, University of Zagreb, and Magyar Tudomanyos Akademia. However, it can be seen that Számítástechnikai és Automatizálási Kutatóintézet is ranked second in terms of the number of citations. Apart from that, Magyar Tudomanyos Akademia is in third place with the highest number of citations even though this institution is ranked last in the number of documents. There are several institutions that have a small number of citations even though they have more documents, such as Pannon Egyetem, and Universiti Malaysia Perlis (Table 4).

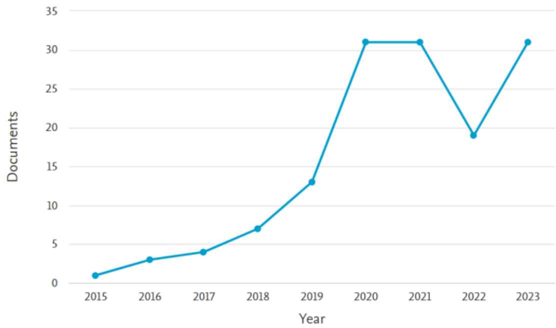

Fig. 2. Publications by year

Table 3. Geographic distribution by country

Rating	Country	Document	Citation	Average Citations
1	Malaysia	19	170	8.95
2	India	14	282	20.14
3	Indonesia	11	59	5.37
4	Hungary	10	169	16.90
5	Czech Republic	8	115	14.37
6	Germany	8	896	112.0
7	Italy	7	246	35.14
8	United Kingdom	7	34	4.86
9	Brazil	5	117	23.40
10	Portugal	4	286	71.50

Table 4. Geographic distribution by institution

Ranking	Institution	Document	Citation	Average Citations
1	Prague University of Economics and Business	5	109	21.80
2	Pannon Egyetem	5	24	4.80
3	Universiti Malaysia Perlis	5	27	5.40
4	Universiti Kebangsaan Malaysia	4	43	10.75
5	Univerza v Mariboru	4	24	6.00
6	Számítástechnikai és Automatizálási Kutatóintézet	4	80	20.00
7	Universiti Sains Malaysia	3	21	7.00
8	Universiti Teknologi PETRONAS	3	17	5.67
9	University of Zagreb	3	18	6.00
10	Magyar Tudomanyos Akademia	3	47	15.67

3.2. Author with Most Extensive and Influential Documents

The author is the creator of a scientific work or article. The author with the most quotes and works can determine or compare who is an expert in that field. There are a total of 159 authors of works discussing Industry 4.0 readiness that have been identified.

After analysis, there were 10 authors with the most documents discussing industry 4.0 readiness. The first to sixth ranks have the same number of documents, namely 4 documents. Next, ranks seventh to ten also have the same number of documents, namely 3 documents regarding Industry 4.0 readiness. It should be remembered that the most influential documents can be seen from the number of times they are cited. Therefore, the author with the greatest influence regarding Industry 4.0 readiness is Basl, J. from Prague University of Economics and Business, Prague, Czech Republic with a total of 107 quotes (Table 5).

Table 5. Influential writers

Ranking	Author	Institution	Document	Citation	Average Citations
1	Abdullah, N.L.	Universiti Kebangsaan Malaysia, Bangi, Malaysias	4	103	25.75
2	Basl, J.	Prague University of Economics and Business, Prague, Czech Republic	4	107	26.75
3	Hajoary, P.K.	Indian Institute of Technology Madras, Chennai, India	4	27	6.75
4	Hizam-Hanafiah, M.	Universiti Kebangsaan Malaysia, Bangi, Malaysia	4	103	25.75
5	Nick, G.	EPIC InnoLabs Nonprofit Ltd., Budapest, Hungary	4	80	20.00
6	Soomro, M.A.	Teesside University, Middlesbrough, United Kingdom	4	103	25.75
7	Abonyi, J.	Pannon Egyetem, Veszprem, Hungary	3	23	7.67
8	Ali, K.	Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia	3	17	5.67
9	Czvetkó, T.	Pannon Egyetem, Veszprem, Hungary	3	23	7.67
10	Dikhanbayeva, D.	Nazarbayev University, Astana, Kazakhstan	3	4	1.34

There are 140 journal articles identified and several journals have multiple discussion subjects. Among all existing journals regarding Industry 4.0 readiness, journals that discuss engineering stand out more than other journals with a total of 77 documents and 2,472 citations. Next in line is a journal about computer science which has 59 documents and was cited 1,715 times. In third place is a journal on business, management and accounting with 49 documents and 959 citations. There are several fields that have a greater number of documents but have fewer citations, such as mathematics which has 11 documents and is only cited 94 times. Apart from that, there are also journals in other fields such as decision sciences, social sciences, environmental sciences, and others (Table 6).

Table 6. Journal theme

Ranking	Journal	Document	Citation	Average Citations
1	Engineering	77	2.472	32.10
2	Computer Science	59	1.715	29.07
3	Business, Management and Accounting	49	959	19.57
4	Decision Sciences	24	331	13.79
5	Social Sciences	15	153	10.20
6	Energy	11	116	10.55
7	Mathematics	11	94	8.55
8	Environmental Science	8	110	13.75
9	Physics and Astronomy	8	45	5.63
10	Chemical Engineering	7	17	2.43

Document analysis and citations applied to articles can be used to determine recommended journals or articles based on the number of citations. In this case, the article by [30] describes a new empirically based model and its implementation to assess Industry 4.0 maturity in industrial companies in separate manufacturing domains. Furthermore, the work of [33] presents and facilitates understanding of the concept of industry 4.0, its drivers, supporting factors, goals and limitations. Next, [112] tested the company's awareness, readiness and ability to face the challenges of industry 4.0 by considering the special role of MSMEs. [34] explains that industry 4.0 is a concept that represents the adoption of techniques and processes by industrial companies through digitalization, cloud computing, internet of things, and big data to gain competitive advantages in domestic and global markets. Apart from that, there are still several authors who have articles or journals that can be used as references or recommended according to (Table 7).

Table 7. Influential Journal

Ranking	Author	Title	Citation
1	[30]	A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	933
2	[33]	Industry 4.0 concept: Background and overview	559
3	[112]	Industrial revolution - Industry 4.0: Are German manufacturing SMEs the first victims of this revolution?	281
4	[34]	Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union	272
5	[113]	Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review	214
6	[32]	Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers	168
7	[114]	Industry 4.0 readiness in manufacturing companies: Challenges and enablers towards increased digitalization	126
8	[115]	Estimating Industry 4.0 impact on job profiles and skills using text mining	119
9	[116]	Drivers and barriers for industry 4.0 readiness and practice: A SME perspective with empirical evidence	88
10	[44]	Industry 4.0 readiness models: A systematic literature review of model dimensions	79

3.3. Intellectual Structure

In order to understand the intellectual structure of literature about industry 4.0 readiness, the analysis of industry 4.0 readiness that has been written by the author was carried out using VOSviewer software. This tool has checked the characteristics of the document provided by the bibliography of each document. VOSviewer has identified 140 documents contained in Scopus so that it can map the authors who produced works regarding Industry 4.0 Readiness, obtaining 34 items which are divided into 4 clusters. The item or topic of an article related to Industry 4.0 readiness is appropriate (Fig. 3a). The nodes in Fig. 3a are the topics most often used by writers or researchers. The path that connects the nodes explains the relationship between the topics discussed in journals and articles.

Furthermore, VOSviewer has also identified the relationship between Industry 4.0 readiness and other relevant topics (Fig. 3b). Industry 4.0 is connected to 34 research links divided into 4 clusters. Some of the strongest links with industry 4.0 are readiness, digital transformation, readiness assessment, and manufacturing companies. The nodes in Fig. 3b represent the strong relationship of topics or other items to Industry 4.0 readiness with VOSviewer results. The density display mode in Fig. 3c shows that the most research related to industry 4.0 is industry 4.0 readiness, maturity model, readiness assessment, and digital transformation. This is marked with a bright yellow color in Fig. 3c and Fig. 3d. The brighter the color, the more research and documents there will be. Vice versa, the fainter the color, it means there is still little research and documents on that topic. Furthermore, Fig. 3d shows that the geography of research related to industry 4.0 readiness and Fig. 3e explains the researchers whose documents regarding industry 4.0 readiness are most cited.

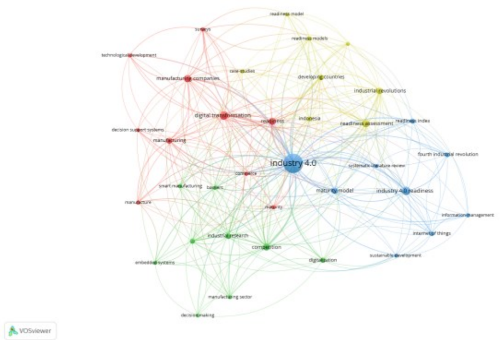

Fig. 3a Network visualization

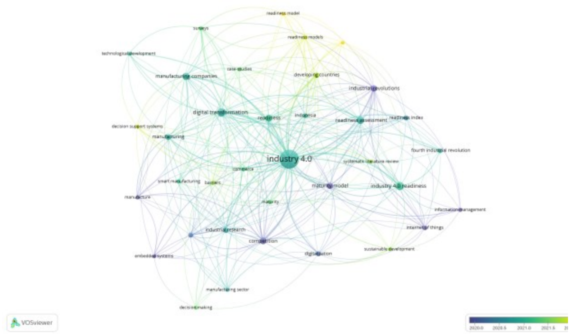

Fig. 3b. Overlay visualization

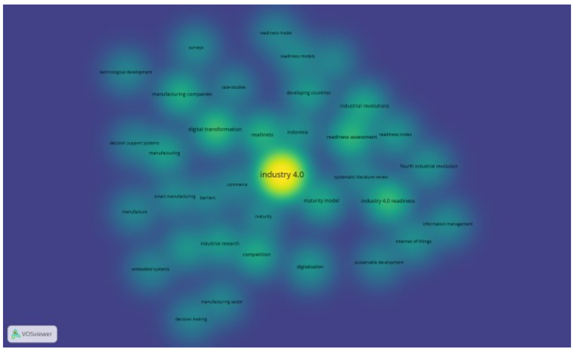

Fig. 3c. Density visualization Co-occurrence

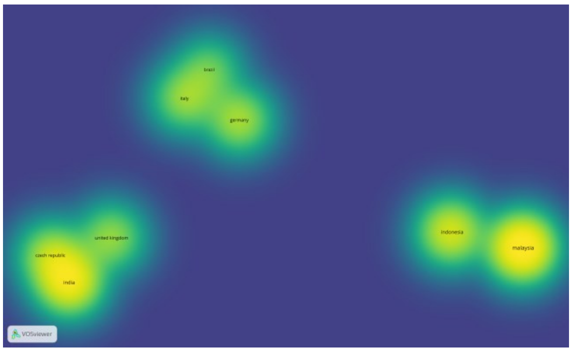

Fig. 3d. Density visualization Co-authorship

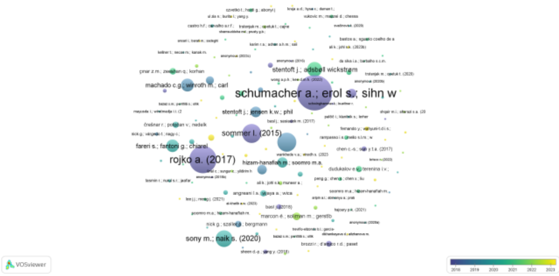

Fig. 3e. Co-Citation

3.4. Discussion

Industry 4.0 is a significant evolution in the world of manufacturing, driven by a number of concepts and technologies that change traditional paradigms [71]. From the early beginning of Industry 4.0, this related research has continued to develop, from 2015 to 2019. However, the decrease in the number of publications in this topic occurred in 2020 to 2021, this could be due to the Covid-19 pandemic. Companies may be hesitant to invest in industry 4.0 related projects due to uncertainty in the current economic climate. Researchers may be focusing on other areas of study that are more pressing or relevant to the pandemic situation. where after the pandemic ended, the research trend about industry 4.0 increased again.

Industry 4.0 readiness involves a deep understanding of several core elements that form the foundation for adopting and integrating advanced technologies. Several elements that must be considered in Industry 4.0 readiness are connectivity via the internet of things (IoT) [22], cyber-physical system integration [80], big data [51], additive manufacturing technology [82], cyber security [46], and human resources [16].

This work uses evaluative and relational bibliometric analysis techniques to analyze 140 articles about Industry 4.0 Readiness found in Scopus from 2015 to the end of 2023. Based on the research conducted, the evolution of knowledge about Industry 4.0 Readiness began in 2015, but the industry variable 4.0 readiness only started to be used frequently in 2019. The industry variable 4.0 readiness has a fairly large growth trend with peaks in 2020, 2021 and 2023 reaching 31 documents and articles. This is supported by the large amount of interest in using the industry 4.0 readiness method in industrial research.

Based on analysis using VOSviewer, there is a correlation between research topics as shown in Fig. 3a. A group of nodes connected to an edge explains the relationship or connection between research topics in the industry 4.0 readiness domain. Bibliometric analysis based on this research topic focuses on two things, namely industry 4.0 and industry 4.0 readiness [55], [85], [112], [114]. The lines or edges in the image indicate a relationship or collaboration between the research topics discussed. In Fig. 3a, industry 4.0 readiness is related to the internet of things [20], [37], industry 4.0 [81], [112], maturity model [18], [30], [83], digital information [25], [55], and manufacturing companies [32], [80].

The results of the overlay visualization are depicted according to Fig. 3b which identifies the research history of researchers in the industry 4.0 readiness variable. This mapping is characterized by nodes that have various colors and edges that connect one researcher to another. Nodes in dark colors indicate research on topics that are most frequently discussed and have been conducted in the past, with the darkest color (purple) representing the year 2020 [56], [74] and the lightest color (yellow) representing the year 2023 [73], [78]. In Fig. 3b, each node has its own color which represents the year the article and journal were published. Most of the research topics related to industry 4.0 readiness analyzed come from 2021 [81], [117], according to the publication graph in Fig. 1.

Furthermore, the density visualization results seen in Fig. 3c identify the level of density or emphasis on nodes which indicate that the research topic groups studied are related to each other. The level of node density in density visualization reflects the extent to which research uses or cites other research as a form of collaboration in the field of Industry 4.0 readiness. The research topic with the highest level of density, which is reflected in the brightest colors, is the industry 4.0 research topic [30], [33], [82], [85]. This indicates that this topic involves a lot of research collaboration with other research topics in the industry 4.0 readiness domain. Exploration of author patterns using VOSviewer has explained the intellectual structure of literature. By using this tool, you can see the mapping of research topics that produce scientific works on Industry 4.0 readiness from 140 works contained in Scopus. In addition, this tool has also checked the document characteristics provided by the bibliography of each document. VOSviewer has also identified interrelationships between variables. Also obtained were variable results that were widely discussed, namely the development of industry 4.0 readiness such as internet of things [20], [37], industry 4.0 [81], [112], maturity model [18], [30], [83], digital information [25], [55], industrial revolutions [112], and manufacturing companies [32], [80].

The density visualization results in Fig. 3d explain the contribution of countries with authors who discuss industry 4.0 readiness. The contribution of the author's country of origin with the highest density is reflected in the lightest colors, namely Malaysia [16], [53], [74] and India [79] which is in accordance with Table 3. Meanwhile, Fig. 3e shows the authors who are most frequently cited. Nodes in dark colors indicate authors who have journals and articles in the past, with the darkest color (purple) representing the year 2018 and the lightest color (yellow) representing the year 2023. The larger circle in Fig. 3e explains that the journals and articles are from that author. often cited by other researchers [30], [33], [112].

In the bibliometric analysis of Industry 4.0 Readiness, it can be seen that this field has experienced rapid development over the last few years. Industry 4.0 offers many opportunities for researchers to explore. There are still many unanswered questions about its impact on industries, and researchers are eager to fill these knowledge gaps. Hence, the number of scientific publications related to Industry 4.0 readiness has increased significantly, indicating strong interest in this field from researchers around the world. These studies cover a wide range of topics, including engineering

[30], [34], [112], computer science [32]- [34], management [71], [113] and business [73], [112], [116], all of which have an important role in understanding readiness to face industry 4.0. Linkages and collaboration between these topics are also visible, reflecting a multidisciplinary approach in Industry 4.0 readiness.

Bibliometric analysis also describes historical trends in industry 4.0 readiness research and highlights the increase in the number of publications over time. It is also apparent that many studies cite other studies, indicating connections and collaborations between these studies. Apart from that, it appears that there are several topics that receive special attention in industry 4.0 readiness research, such as internet of things [20], [37], industry 4.0 [81], [112], maturity model [18], [30], [83], digital information [25], [55], industrial revolutions [112], and manufacturing companies [32], [80].

4. Conclusion

Overall, the bibliometric analysis of industry 4.0 readiness illustrates positive developments in the field of technology and highlights the importance of a multidisciplinary approach and collaboration in better understanding readiness for industry 4.0. This will influence the development of industry 4.0 and future research. However, it should be noted that the type of bibliometric analysis carried out does not have special limitations, because this method is quantitative and analyzes data from articles that have been obtained from Scopus. Even though the search method is carried out carefully, there may still be documents or journals that are outside the scope of the study, which can act as outlier data [99]. Therefore, it is necessary to filter documents that are not relevant, so the author decided to limit himself to only using the article title, abstract and keywords used. It is important to remember that the main limitation in this research is the focus on the field of study related to the industry 4.0 readiness variable. Most publications discuss the application of Industry 4.0 readiness in various fields, allowing comparisons with previous research [107]. While VOSviewer is a useful tool for exploring and visualizing the literature related to industry 4.0 readiness, it is important to be aware of its limitations and potential biases in order to fully understand the results of any analysis done using the tool. the potential for bias in bibliometric analyses, as they rely heavily on what is already published and available in the literature. Hence, the future research should aim to provide a more comprehensive and refinement understanding of Industry 4.0 readiness, while also exploring ways to address the challenges and barriers to adoption.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Funding: This research was funded by the name of FUNDER, grant number XXX.

Conflicts of Interest: The authors declare no conflict of interest.

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